The Research Foundation
of State University of New York

The University at Stony Brook
OFFICE OF SPONSORED PROGRAMS
Stony Brook, NY 11794-3366
Telephone: 516-632-9039 Fax: 516-632-6963

August 29, 1997

Dr. Deborah Van Vechten, Program Officer
US Navy Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Re: Grant No. N00014-95-1-0762

Dear Dr. Van Vechten:

Enclosed please find three (3) copies of the annual progress report for the above referenced project.

Please contact me at (516) 632-9079 if you should have any questions concerning this submission.

Sincerely,

Glen Itzkowitz
Sponsored Programs Coordinator

GI:bb
Enc.

XC: Dr. M. Gurvitch
Administrative Grants Officer (1)
Director, Naval Research Laboratory (1)
Defense Technical Information Center (2)
file 431-0318A

Department of Physics and Astronomy
State University of New York at Stony Brook
Stony Brook, NY 11794-3800

Mechanism of Charge Transfer Across Highly Transparent S-N Interfaces in High Temperature Superconductors

(Progress Report)

Reporting Period:
August 1996 - July 1997

Prepared by:
Dr. Sergey K. Tolpygo and Prof. Dmitri Averin

Sponsoring Organization:
Office of Naval Research

Grant No. N00014-95-10762
Project P.I.: Prof. Michael Gurvitch
Co-P.I.s: Prof. D. Averin and Dr. S. Tolpygo

Report Prepared For:
Dr. Deborah Van Vechten, Program Manager

UNCLASSIFIED

August 21, 1997

As in the previous years, our efforts were applied on both the experimental and theoretical sides of the project and were aimed at investigation of the stationary and nonstationary properties and mechanisms of current transfer across SN interfaces.

Major Accomplishments

We have studied the influence of various technological parameters (irradiation dose, spot size, writing time, etc.) on stationary and nonstationary properties of Josephson junctions fabricated by direct electron beam writing and have developed an understanding of the proximity effect and the size and temperature dependence of the Josephson critical current in this type of high-T_c Josephson junctions. Based on the studies of the physical properties of irradiated YBCO films and the defect formation at electron irradiation which were performed during the previous reporting periods, we have developed a quantitative model of the e-beam-made junctions [1]. This model takes into account the space distribution of the radiation-induced defects which arises due to the gaussian distribution of the electron density in the incident beam and beam spreading within the film. As a result of this distribution, the interface between the e-beam-damaged and undamaged YBCO is not sharp, and hence the e-beam junctions present an SS'N'S'S structure, where N' is a "normal metal" barrier. This in fact is a highly disordered superconductor in which the critical temperature is strongly suppressed (or zero) due to a high concentration of radiation-induced pair breaking defects (in-plane oxygen vacancies). The size of this N' region (junction length L) in high quality junctions was found to be ~ 5 nm, i.e. $L/\xi_N(T_c)$ is ~ 3, where $\xi_N(T)$ is the coherence length. The S is a "clean" superconductor (unmodified YBCO), and S' is a superconductor with slightly reduced critical temperature, i.e. low concentration of pair breaking defects.

We have found that the onset of the critical current in the e-beam junctions (the junction critical temperature) is determined by the reduced critical temperature of the S' near the interface. We have also found that the intrinsic temperature dependence of the critical current density j_c in e-beam junctions is close to a power law dependence $(1-T/T_c)^n$ with $n \sim 2$ [2,3], i.e. much weaker than in other types of high-T_c SN'S junctions, e.g. in Co-doped YBCO or Ca-doped YBCO. In those junctions j_c depends on temperature exponentially $[\exp(-L/\xi_N(T))]$ due a strong temperature dependence of the coherence length. However, in the e-beam junctions the coherence length in the barrier region is almost temperature independent and is basically determined by the length of electron diffusion between pair breaking scattering events. Both the short junction length and the weak $j_c(T)$ dependence are advantageous in applications because they conspire in a way that allows a lower spread of critical currents in multijunction circuits to be achieved.

We have also studied the limitations on the critical current in e-beam junctions imposed by the self-field effect (i.e. the crossover from narrow to wide junction behavior). We found that the region of narrow junction behavior in thin-film planar junctions is larger than in the sandwich-type junctions due to a larger Josephson

penetration depth [2,3]. The crossover is independent of the junction width and occurs at critical currents $I_c \sim 1$ mA. The obtained results allow for an easy determination of the magnetic field penetration depth λ in the banks of thin-film junctions from the $I_c(T)$ dependence. The extracted values of λ were found to be in good agreement with the results obtained by other methods, e.g. from the inductance of thin-film dc SQUIDs (see the previous Progress Report).

Another direction of our work during the reporting period was the experimental investigation of the nonstationary properties of highly transparent junctions, in particular the shape of I-V characteristics, the nature of the excess current, and the effects of thermal noise. The results were found to be in agreement with the theory based on multiple Andreev reflections which was developed in the theoretical part of the project (see below). A new direction of this work is an ongoing investigation of the transition from the Josephson to flux flow behavior which occurs in junctions with high critical current densities as well as other aspects of vortex dynamics in and near the junction. The motivation for this work is the fact that the j_c in high quality junctions can reach the value of the depairing critical current density, while the current density in the neighboring regions is limited by a much lower (about two orders of magnitude) value which is established by the pinning strength. Therefore, in real junctions the critical current can be limited by flux pinning and flux creep phenomena in the junction banks.

An interesting spin-off of our work on e-beam writing technology was the investigation of the influence of electron irradiation on the Josephson properties of biepitaxial grain boundary junctions [4]. It was found that the junction parameters can be modified (and improved) in a controllable fashion by applying a radiation dose to the grain boundary region. The procedure can be used in circuit design and testing to modify the parameters of one or a few selected junctions in order to achieve the desired device performance. Although only biepitaxial junctions were studied, we anticipate that the technique may be applied to modify other types of grain boundary and step-edge junctions.

We also continued to build on understanding of the influence of in-plane oxygen defects on the physical properties of high-T_c superconductors, in particular on the critical magnetic field H_{c2}. It was found that the same pair breaking parameters and scattering rates which were extracted from the resistivity and the T_c suppression rate (see the previous Progress Report) allow also for a self consistant description of changes in H_{c2} [5].

The theoretical part of our effort during the last year was focused on the theory of the ac Josephson effect and noise in high-transparency Josephson junctions. This work extends the theory that was developed earlier in the course of the current grant and describes electron transport properties of Josephson junctions in terms of cycles of multiple Andreev reflections (MAR). The predictions of our theory (for review see [6]) both for the dc current and supercurrent noise were recently confirmed in experiments [7,8]. Therefore, it was important to extend further the theory in several directions. In

particular, our theory of MAR was originally formulated for a single-mode quantum channel, and we extended it first to the multi-mode conductors with arbitrary electron scattering properties. This was done both within a simple approach based on the Bogolyubov-de Gennes equations [9] that is suitable for junctions between the BCS superconductors, and also with Green's function technique [10] which is appropriate for superconductors with non-trivial microscopic structure, for example strong electron-phonon coupling. This allowed us for the first time to make quantitative predictions for the current-voltage (I-V) characteristics of regular SNS junctions with diffusive electron transport in the N-region. In particular we have shown that MAR in the SNS junctions should lead to the characteristic $V^{-1/2}$ divergence of the differential conductance of the junction at low voltages.

Another direction for the extension of the MAR theory was towards accounting of the finite external impedance of the junction [11]. All previous theories of MAR were constructed under the assumption that the junction is biased by an ideal dc voltage source with zero impedance. Such a model does not describe correctly the transition between the supercurrent branch of the I-V characteristic and the finite-voltage branch. We developed an adiabatic approach which allows for a quantitative description of the transition region, and calculated I-V characteristics of a resistively shunted ballistic point contact in the wide temperature range. The I-V characteristics depend strongly on the number of transverse electron modes supported by the point contact. We considered two opposite limits – quantum single-mode contact and classical point contact with a large number of transverse modes. The results for the classical contact are found to be in good agreement with the experimental I-V characteristics of the high-transparency HTS junctions fabricated by direct e-beam writing.

References

[1] S.K. Tolpygo "Proximity effect and stationary Josephson properties of e-beam junctions", to be published.

[2] S.K. Tolpygo and M. Gurvitch, "Critical currents and Josephson penetration depth in planar thin-film high-T_c Josephson junctions", Appl. Phys. Lett. **69**, 3914 (1996).

[3] S. K. Tolpygo and M. Gurvitch, "Critical currents, proximity effect, and Josephson penetration depth in planar high-T_c Josephson junctions," IEEE Trans. Appl. Supercond. 7, 3208 (1997).

[4] F. Tafuri, S. Shokhor, B. Nadgorny, M. Gurvitch, F. Lombardi, and A. Di Chiara, "Electron beam irradiation of YBCO grain boundary Josephson junctions", Appl. Phys. Lett. **71**, 125 (1997).

[5] J.-Y. Lin, H.D. Yang, S.K. Tolpygo, and M. Gurvitch, "T_c suppression and upper critical field H_{c2} in YBCO with in-plane oxygen defects," Czech. J. Phys. **46**, Suppl. S3, 1187 (1996).

[6] D.V. Averin, ``Theory of ac Josephson effect and noise in superconducting constrictions", in: Physics and Applications of Mesoscopic Josephson Junctions, ed. by H. Ohta and C. Ishii, (Universal Academy Press, Tokyo, 1997), to be published.

[7] E. Scheer, P. Joyez, D. Esteve, C. Urbina, and M.H. Devoret, Phys. Rev. Lett. **78**, 3535 (1997).

[8] P. Dieleman, H.G. Bukkems, T.M. Klapwijk, M. Schicke, and K.H. Gundlach, "Observation of Andreev reflection enhanced shot noise", preprint (1997).

[9] A. Bardas and D.V. Averin, "Electron transport in mesoscopic disordered SNS junctions", Phys. Rev. B **56**, (1997).

[10] A.V. Zaitsev and D.V. Averin, "Theory of ac Josephson effect in superconducting constrictions", submitted to Phys. Rev. Lett.

[11] D.V Averin, A. Bardas, and H.T. Imam, "Resistively shunted superconducting quantum point contacts", to be published.